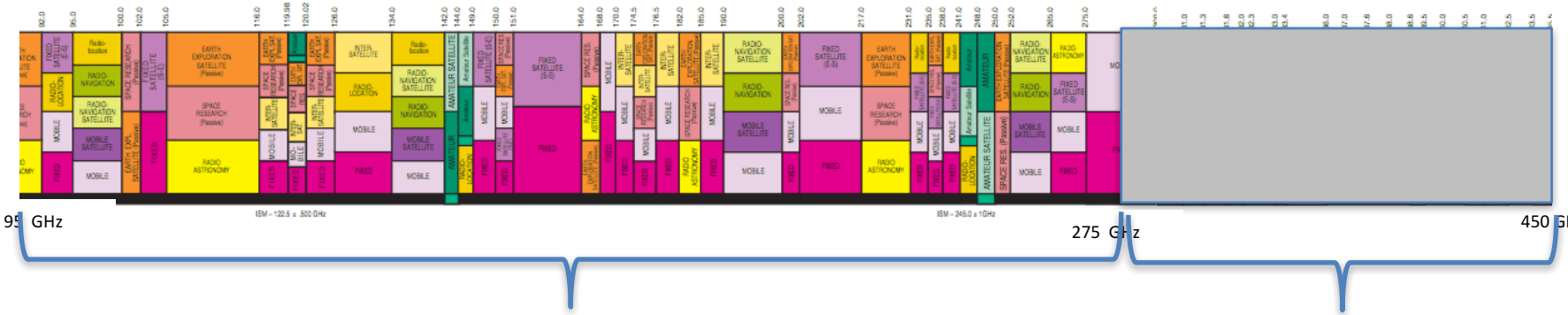


Opening 95-475 GHz to Commercial Use: Technical and Policy Challenges

Michael J. Marcus, Sc.D., F-IEEE

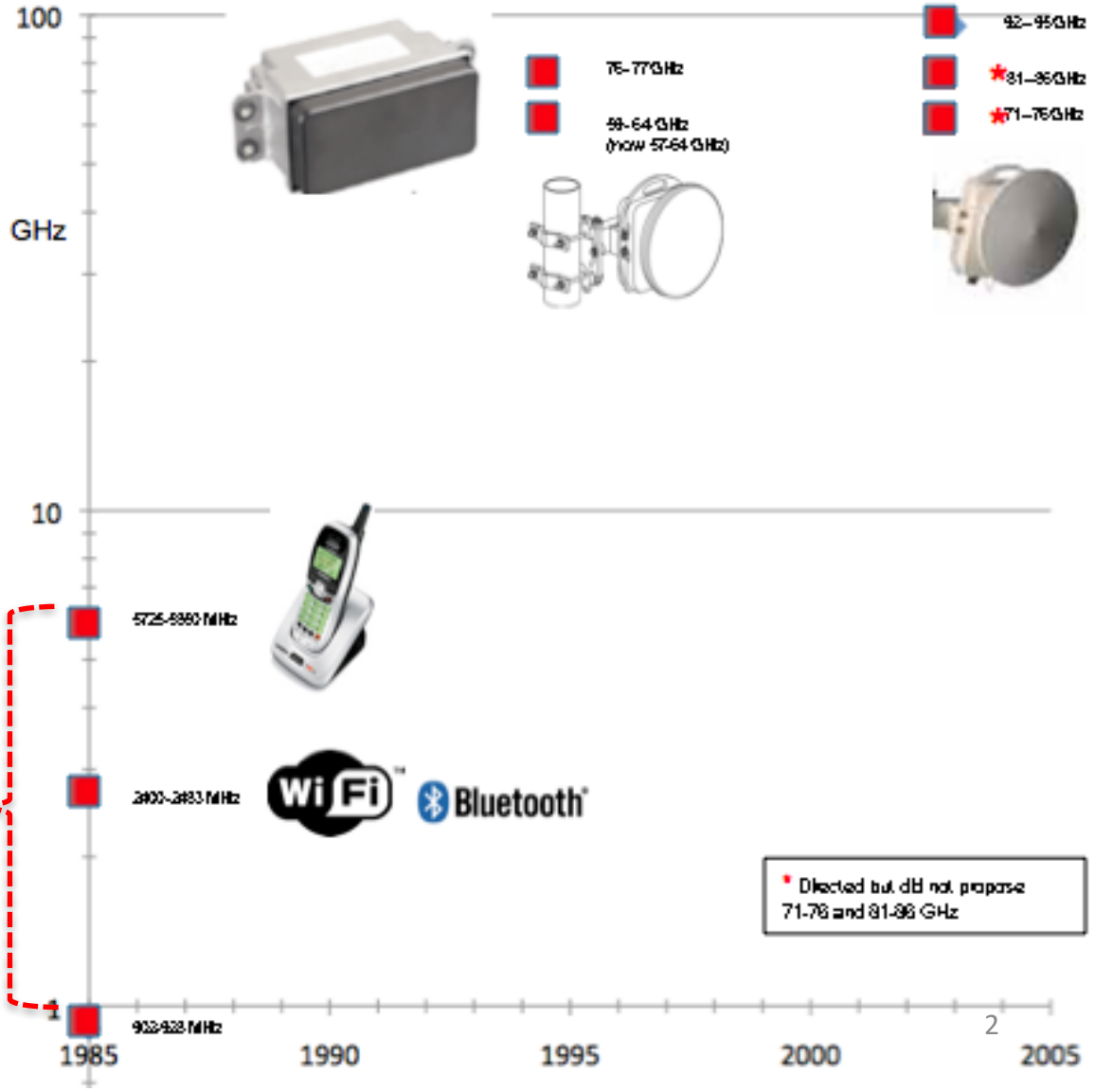
Adjunct Professor of ECE, Virginia Tech
Past Chair, IEEE-USA Committee on Communications Policy
Associate Chief, FCC Office of Engineering and Technology (Retired)
Director, Marcus Spectrum Solutions LLC

mjmarcus@marcus-spectrum.com

N3JMM/7J1AKO

My background:

Creation of regulations that enabled Wi-Fi & Bluetooth 5/85



Why > 95 GHz

Let's learn from Willie Sutton:

Show Me The Money

- **Willie Sutton, a notorious American bank robber of a half century ago, was once asked why he persisted in robbing banks. *"Because that's where the money is."***

Willie Sutton
FBI Photo

>95 GHz is "where the spectrum is"!

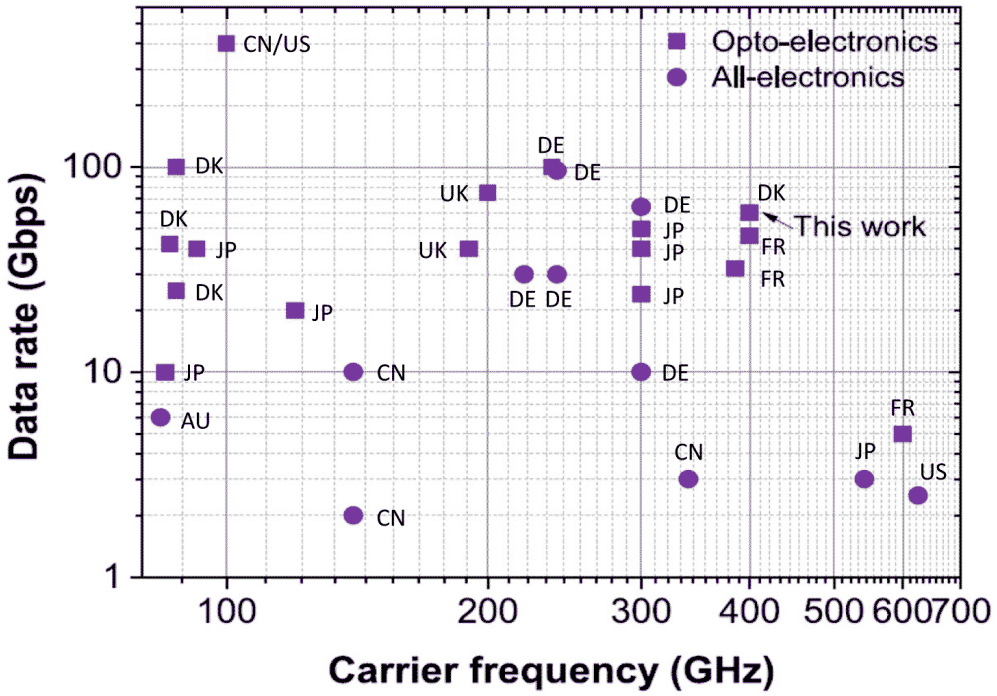
(If you need large bandwidth)

This Technology Has Been Used Outside of Laboratory Already

- NTT 125 GHz system used at 2008 Beijing Olympics

https://www.ntt-review.jp/archive/ntttechnical.php?contents=ntr200903sf3.html

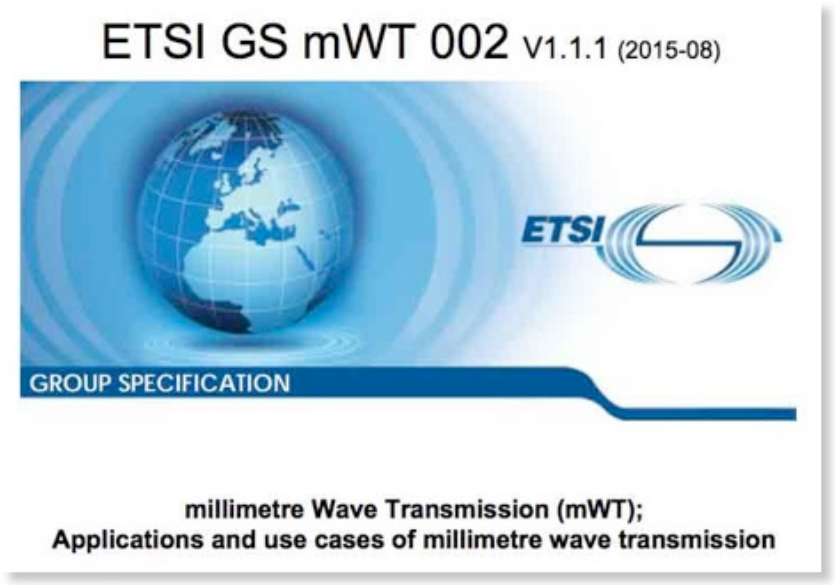
Published Data on mmW/THz System Experiments



- R&D, often with national government support, is underway around the world as high as 600 GHz!

Yu, Asif, *et al.*, "400-GHz Wireless Transmission of 60-Gb/s Nyquist-QPSK Signals Using UTC-PD and Heterodyne Mixer," *IEEE Transactions on Terahertz Science and Technology*, Issue No. 99, p. 1-6 (August 2016) (http://ieeexplore.ieee.org/document/7556985/)

Europe, Inc. is Targeting This Technology



- "With respect to the aforementioned, the mission of ETSI ISG mWT is to promote the use of millimetre wave spectrum from 50 GHz up to 300 GHz for present and future critical transmission applications and use cases. Moreover, ETSI ISG mWT will focus on enhancing the confidence of all stakeholders and the general public in the use of millimetre wave technologies"

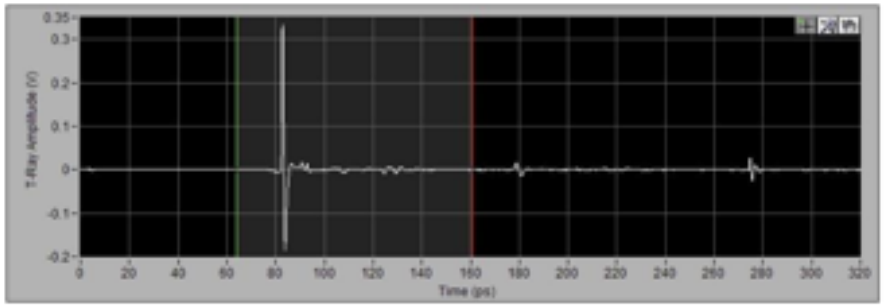
http://www.etsi.org/deliver/etsi_gs/mWT/001_099/002/01.01.01_60/gs_mWT002v010101p.pdf

Possible Communications Uses of 95-450 GHz

- Point-to-point terrestrial communications
  - If large bandwidth channels are available could achieve rates comparable to optical fiber
  - While fiber hardware is always less expensive, in some cases installation costs can be huge
  - While fiber can be repaired quickly in case of cuts from construction accidents, quick repair may not be possible after *some* types of disasters
    - *e.g.* earthquake with ground rupture
  - Lower time latency than fiber

Possible/Actual Practical Uses of 95-450 GHz

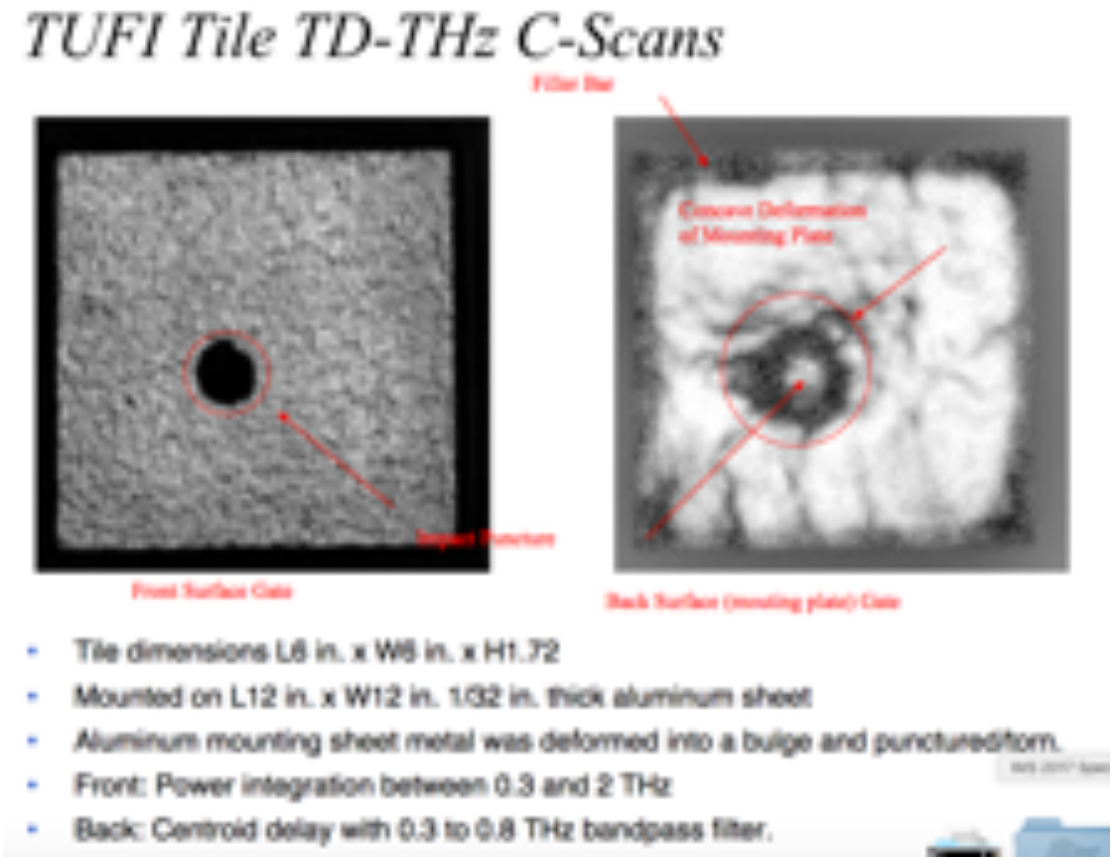
- THz Spectroscopy
  - Useful for both scientific research and some industrial operations
  - Two versions (analogous to UWB):
    - "time domain"



Frequency 0.05 – 4 THz
Wavelengths 6 – 0.1 mm
cm^{-1} 1.7 - 100

    - "frequency domain"
      - Stepped frequency
  - cm ranges, generally indoor, very low power

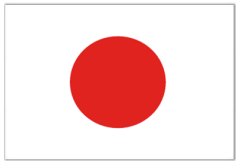
Use of THz Spectroscopy in NASA Space Shuttle Program



Applications of THz Spectroscopy

- Study of
  - Polymers
  - Semiconductors
  - Ceramics and glasses
  - Organic molecules
  - Gas spectroscopy
  - Conductive films
  - Liquid crystals
  - Composites
  - Oils
  - Nondestructive testing
- Aircraft Non-destructive Testing
- Examination of Packaged Goods
- Spacecraft Non-destructive Testing
- Radome Inspection
- Pipeline Repair Inspection
- Monitoring production lines of plywood

Current THz Spectroscopy Products



- **ADVANTEST TAS7500 Series Terahertz Spectroscopic / Imaging System**
  - "The TAS7500 series is a family of compact and multipurpose terahertz spectroscopic / imaging systems. Utilizing the unique properties of the terahertz region (0.1 – 10.0THz) of the electromagnetic spectrum, these systems perform non-destructive analysis of pharmaceuticals, chemicals, communications materials, etc., without requiring a specially constructed analysis environment. Speed and ease of operation are the hallmarks of Advantest's terahertz analysis systems. In addition to industrial applications, the TAS7500 series is also an optimal choice for terahertz – related research, leveraging Advantest's high-precision detection technology to provide best-in-class sampling performance".

https://www.advantest.com/products/terahertz-spectroscopic-imaging-systems/tas7500-series-terahertz-spectroscopic-/-imaging-system

- **LUNA Luna Innovations/Advanced Photonix T-Gauge®**
- "T-Gauge®Picometrix sensor is the first web scanning Time Domain Terahertz solution for plant floor deployment to measure basis weight, caliper, density, moisture on laminated and multi-layer composites. Terahertz technology previously limited to research facilities, military, aerospace and homeland security is now available to the industrial web processing market."

http://lunainc.com/thz/products/t-ray5000

Quote from a Former Chief, OET

- "If you are looking for interesting ideas in spectrum policy, take things that people are doing illegally *without causing problems* and make them legal!"
  - Is THz spectroscopy a good example?

>95 GHz Issues

- Existing ITU and US allocations go to 275 GHz but US “service rules” end at 95 GHz
  - Minor exceptions for amateurs and ISM
  - Technology >95 GHz faces uncertain delays before market access
- ITU rules for passive spectrum are more burdensome >95 GH than in UHF!
  - High density of passive allocations
  - RR 5.149 & 5.340 impact terrestrial transmitters

RR 5.149

5.149 In making assignments to stations of other services to which the bands* 94.1-100 GHz, 102-109.5 GHz, 111.8-114.25 GHz,128.33-128.59 GHz,129.23-129.49 GHz,130-134 GHz, 136-148.5 GHz,151.5-158.5 GHz, 168.59-168.93 GHz, 171.11-171.45 GHz,172.31-172.65 GHz,173.52-173.85 GHz,195.75-196.15 GHz are allocated, administrations are urged to take all practicable steps to protect the radio astronomy service from harmful interference. Emissions from spaceborne or airborne stations can be particularly serious sources of interference to the radio astronomy service (see Nos. 4.5 and 4.6 and Article29). (WRC-07)

* Only bands in 95-200 GHz listed here)

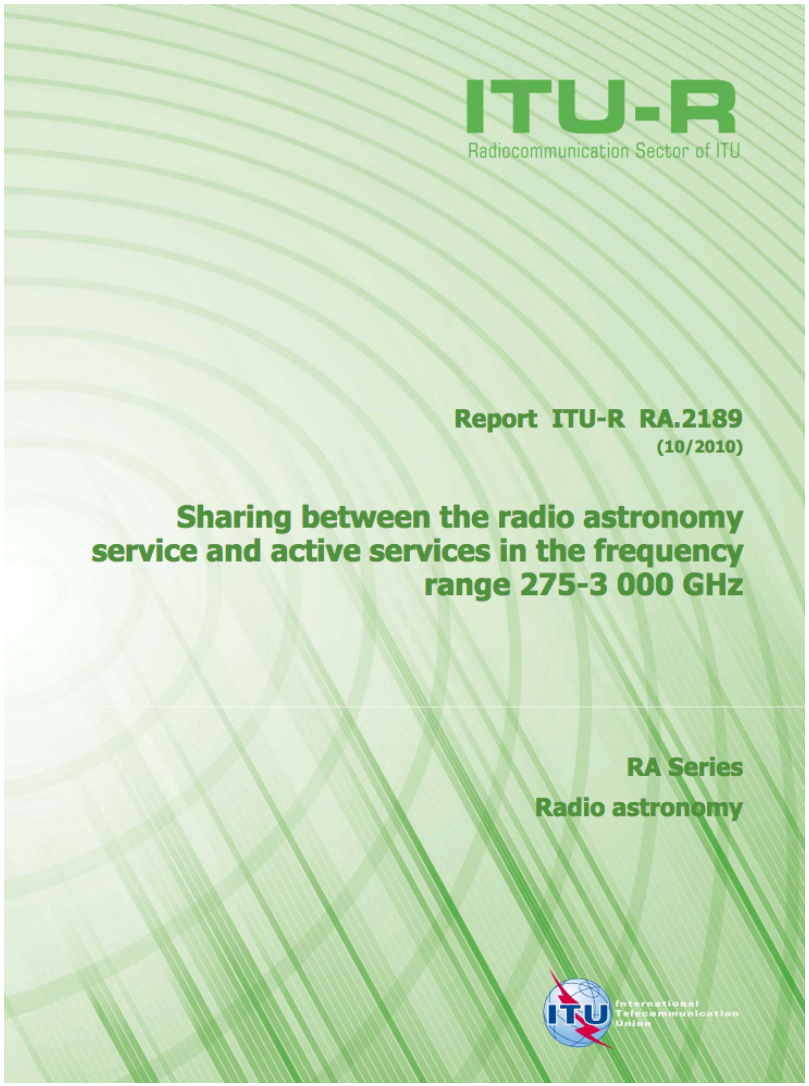
RR 5.340/US246

5.340 All emissions are prohibited in the following bands*:

100-102 GHz, 109.5-111.8 GHz, 114.25-116 GHz, 148.5-151.5 GHz, 164-167 GHz, 182-185 GHz, 190-191.8 GHz,

* Only bands in 95-200 GHz listed here)

Is Sharing Possible?



- 2010 ITU-R report indicates that sharing above 275 GHz is possible for radio astronomy and terrestrial users.
  - Does not address environmental sensing
- Is 275 GHz a physical limit or bureaucratic one?

http://www.itu.int/pub/R-REP-RA.2189-2010

Isn't Sharing at >95 GHz Different than UHF Sharing?

- At what frequency limit is physics so different that approaches of RR 5.149 & 5.340 have a very different cost/effectiveness ratio than at UHF?
- ITU-R has already addressed special case of radio astronomy >275 GHz and found terrestrial sharing possible
  - 275 GHz limit of study chosen for bureaucratic reasons not physical ones!
  - Environmental sensing sharing is much more difficult

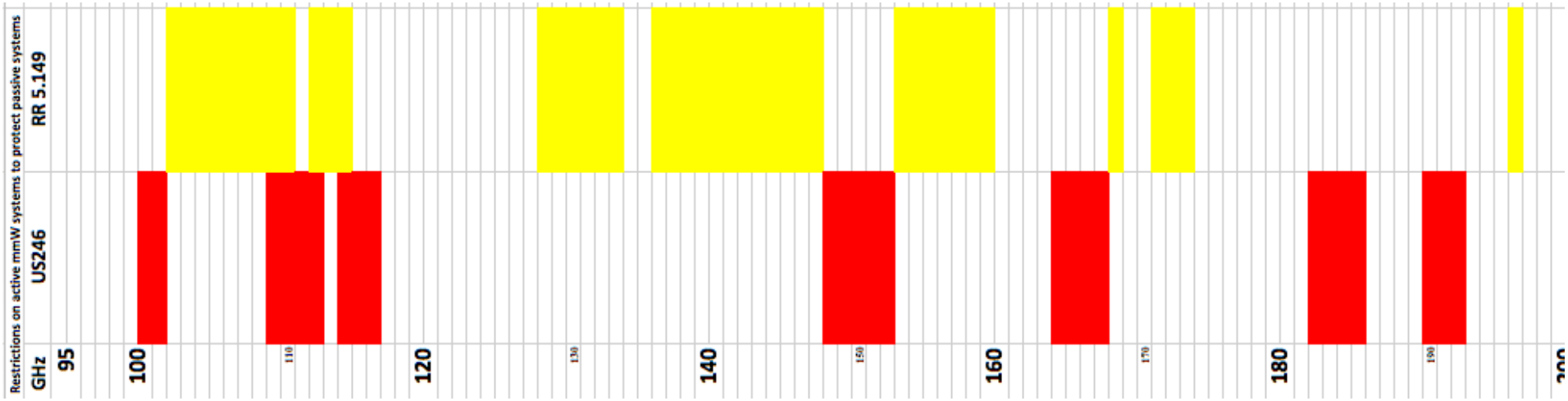
Possible Sharing with Environmental Sensing

- 2 cases: GSO and NGSO
- GSO case
  - FS/FSS sharing has been in operation since 1970s
  - Basic approach is to keep FS power beams away from GSO arc
  - Coordination required and effective in sharing

Possible Sharing with Environmental Sensing

- 2 cases: GSO and NGSO
- NGSO case
  - Unlike GSO case, NGSO passive receivers can be anywhere in sky
  - Similar to GSO/NGSO sharing which has been implemented in past decade
  - Alignment events can be predicted months in advance and terrestrial transmitters then modify spectrum use before alignment event

Cumulative Impact of Passive Bands



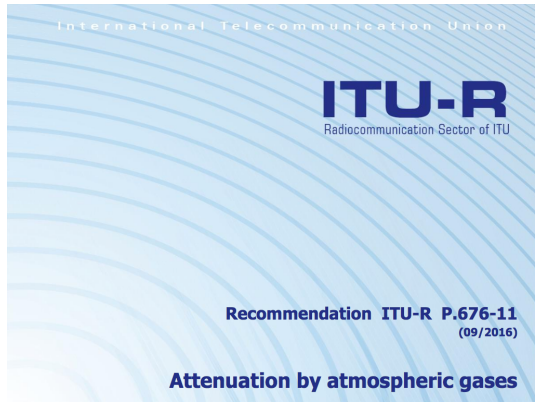
95-200 GHz in US

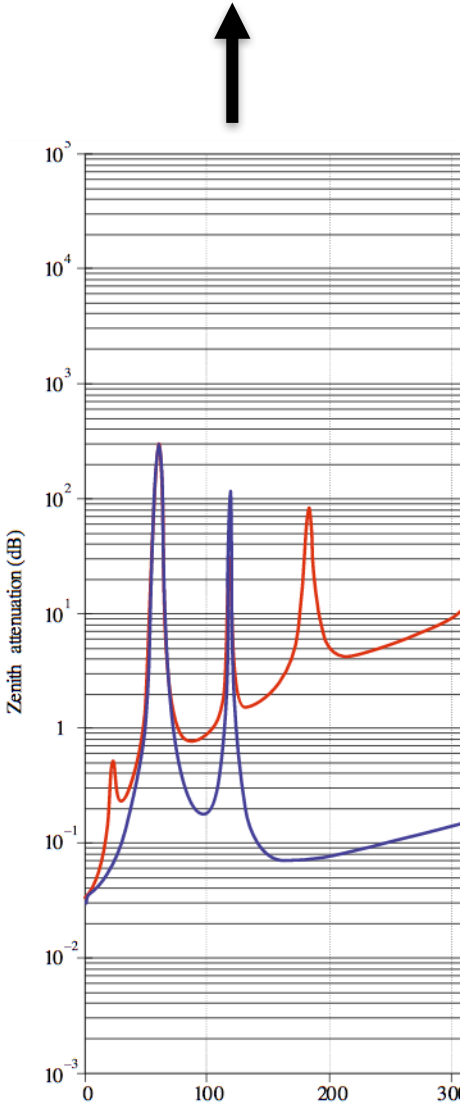
Category of Passive Protection	Total Such Spectrum in 95-200 GHz (GHz)	Fraction of Band with Protection
Primary Passive Allocation	16.85	16%
Coprimary Passive Allocation	53.9	51%
Protection under RR 5.149	35.7	34%
Protection under RR 5.340	16.85	16%
Protection under US 246	16.85	16%

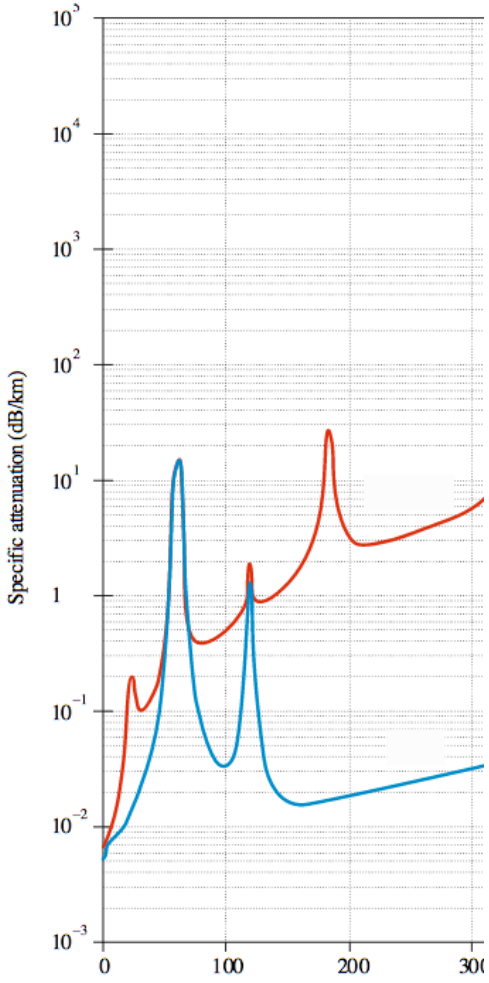
Frequency Band	Bandwidth
122.25-130 GHz	7.75 GHz
158.5-164 GHz	5.5 GHz
167-174.8 GHz	7.8 GHz
191.8-200 GHz	8.2 GHz

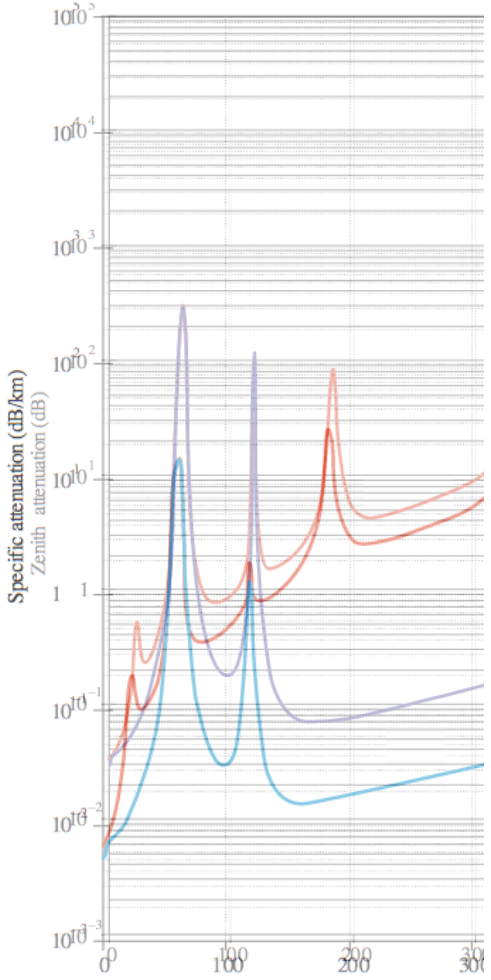
Spectrum available now <u>without</u> passive sharing

Vertical and Horizontal Propagation Differs!









WRC-19 Agenda Item 1.15

- Resulted from apparent Japanese initiative in APT conference preparation
- Parallel CEPT initiative
- WRC-15 took text from one and the frequency range from the other
  - a typical ITU compromise!

WRC-19 Agenda Item 1.15

RESOLUTION 767 (WRC-15)

Studies towards an identification for use by administrations for land-mobile and fixed services applications operating in the frequency range 275-450 GHz

The World Radiocommunication Conference (Geneva, 2015),

considering

a) that a number of bands in the frequency range 275-1 000 GHz are identified for use by administrations for passive services, such as the radio astronomy service, the Earth exploration-satellite service (passive) and the space research service (passive);

b) that No. 5.565 states that the use of the range above 275 GHz by the passive services does not preclude use of this range by active services;

.
.
.

resolves to invite the 2019 World Radiocommunication Conference

taking into account the results of ITU-R studies on sharing and compatibility between passive and active services as well as spectrum needs for those services, to consider identification for use by administrations for the land-mobile and fixed service applications operating in the frequency range 275-450 GHz, while maintaining protection of the passive services identified in No. 5.565, and take appropriate action,

>275 GHz Spectrum and RR 5.565

5.565 The following frequency bands* in the range 275-1000 GHz are identified for use by administrations for passive service applications:

–radio astronomy service:

275-323 GHz, 327-371 GHz, 388-424 GHz, 426-442 GHz, 453-510 GHz,

–Earth exploration-satellite service (passive) and space research service (passive):

275-286 GHz, 296-306 GHz, 313-356 GHz, 361-365 GHz, 369-392 GHz, 397-399 GHz, 409-411 GHz, 416-434 GHz, 439-467 GHz,

The use of the range 275-1000 GHz by the passive services does not preclude use of this range by active services. Administrations wishing to make frequencies in the 275-1000 GHz range available for active service applications are urged to take all practicable steps to protect these passive services from harmful interference until the date when the Table of Frequency Allocations is established in the above-mentioned 275-1000 GHz frequency range.

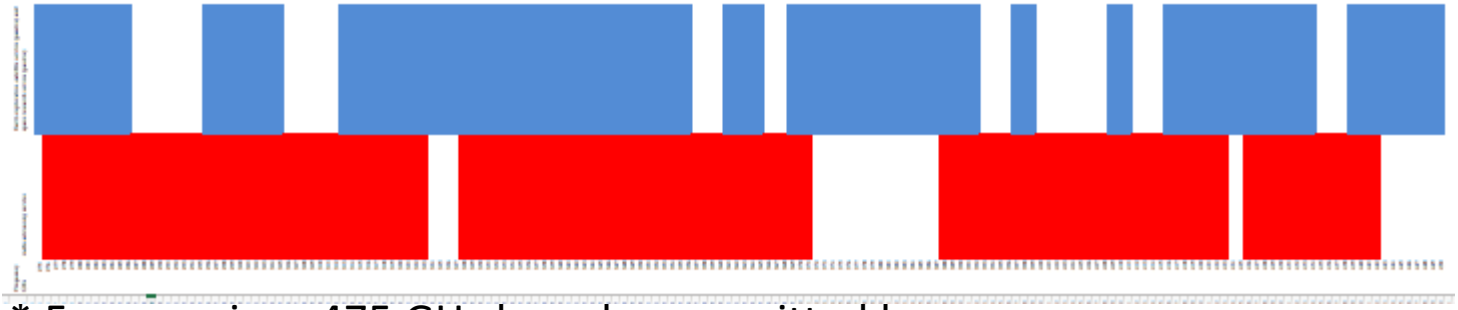
* Frequencies >475 GHz have been omitted here

>275 GHz Spectrum and RR 5.565

- All spectrum in 275-450 is listed for protection in RR 5.565
- Unlike 5.340, only “all practicable steps” are required
- If we accept ITU-R RA.2189, we only need focus on environmental sensing bands

ES

RA

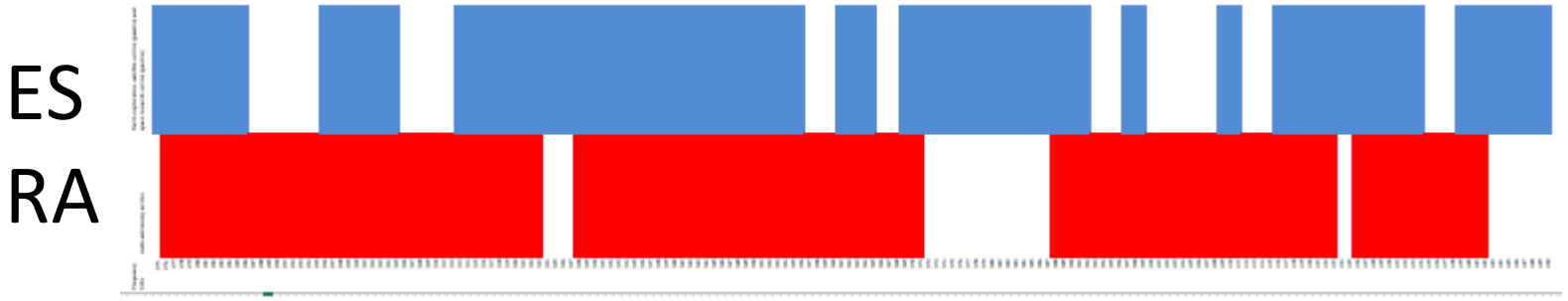


* Frequencies >475 GHz have been omitted here

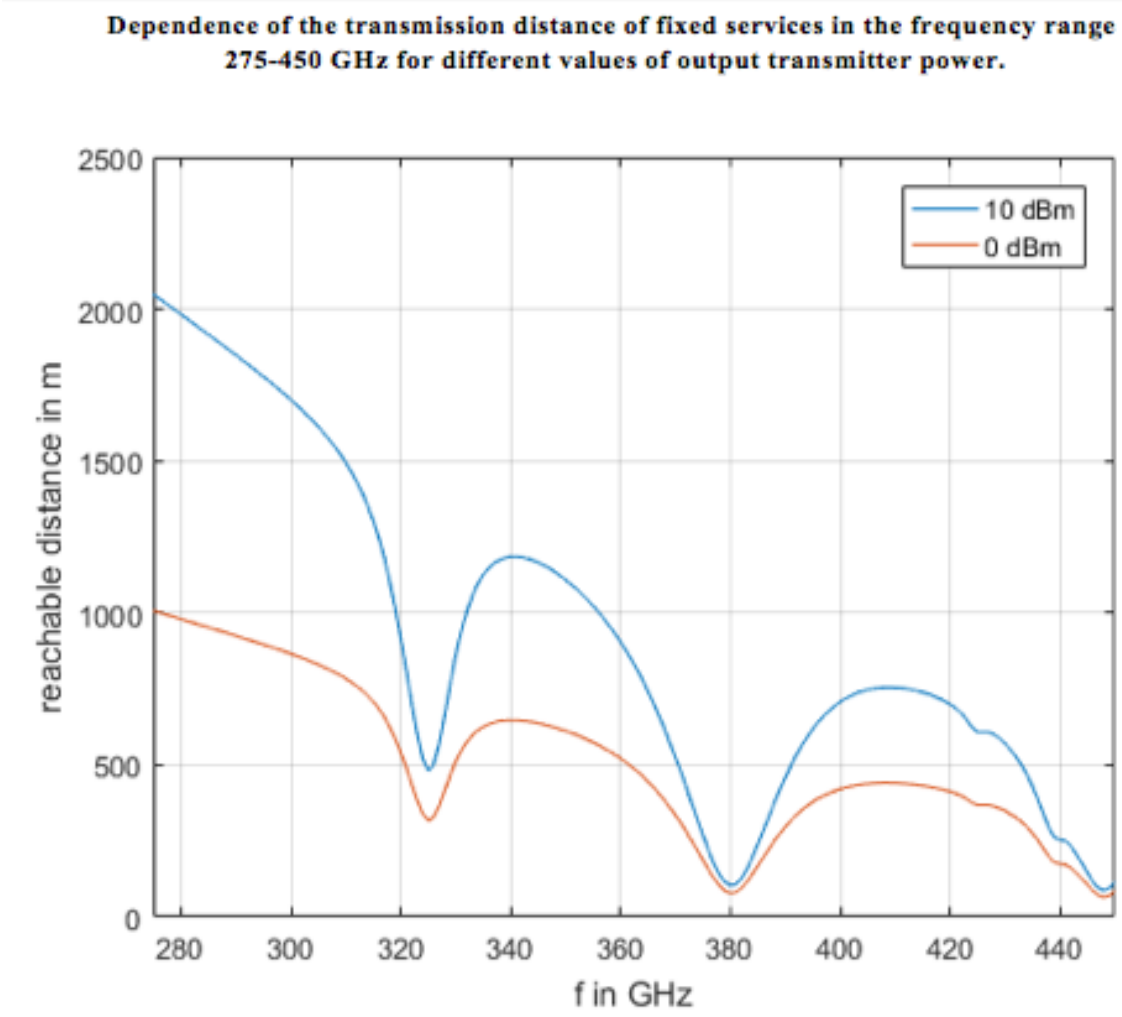
>275 GHz Spectrum and RR 5.565

- Environment sensing identified bands are 141 GHz out of 175 GHz total in 275-450 GHz
- If sharing with environment sensing is *not* possible, largest clear blocks *are only 10 GHz* BW (286-296 GHz and 399-409 GHz)

→ Sharing is essential for any practical use of this spectrum!



Item 1.15 Status



- US totally silent to date!
- In November in SG 5
  - Germans proposed use of 275-321.8 GHz and 380-445 GHz
  - Japanese proposed use of 275-316 GHz

Based on the estimated application range of 500m the following frequency bands are possible candidates: 275-322 GHz, 329-364 GHz. The frequency band between 392-432 GHz is a candidate if the transmit power exceeds 0 dBm.

Key Issues

- Importance of international harmonization
  - More consistently important in Japan than in US
  - FCC acted without ITU in original unlicensed 2.4 GHz band (Wi-Fi & Bluetooth) and 60 GHz unlicensed
  - Since 1987 FCC has not standardized mobile technologies
    - This is why Qualcomm is a US company
    - New FCC standardization is unlikely in 5G in US

Key Issues

- Importance of international harmonization
  - Are worldwide economies of scale essential for mmW/THz implementation?
  - Is more timely implementation before worldwide consensus desirable?

Key Issues

- RF Safety
  - FCC has no RF safety numeric limits >100 GHz and none proposed
- Capital Formation for R&D/US Competitiveness
  - Foreign competitors have access to government cost sharing for this R&D
  - US firms depend on private capital formation
  - FCC track record on RM-11713 and Docket 13-259 would discourage most VC's with other options for investing in technology

Questions?